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Diode lasers with asymmetric barriers for 850 nm spectral range: experimental studies of power characteristics

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Abstract. It is demonstrated that the use of asymmetric barrier layers in a waveguide of a diode laser suppress non-linearity of light-current characteristic and thus improve its power characteristics under high current injection. The results are presented for 850-nm AlGaAs/GaAs broad-area lasers with GaInP and AlInGaAs asymmetric barriers.

1. Introduction

It was proposed to use so-called asymmetric barrier layers (ABLs) on both sides of active region to improve temperature stability of diode lasers [1]. As shown on Fig. 1, ABL that is on *n*-emitter side should pass only electrons and another ABL, on *p*-emitter side, should pass only holes. Such selectivity of ABLs is achieved through formation of a high energy barrier in one band (e.g., in conduction band for *p*-ABL) together with negligible barrier in another band (in valance band for *p*-ABL) at the ABL/waveguide heteroboundary. As a result, charge carriers in such laser coexist and, consequently, recombine only in the active region. Implementation of this concept is aimed at suppression of parasitic recombination in waveguide layers – the main problem of diode lasers with small localization energy of charge carriers in the active region, which in particular leads to decrease of efficiency of conversion of electrical energy into energy of laser radiation. The most pronouncedly this issue appears in structures with broad waveguide [2], at elevated temperatures [3] and under high pumping [4].

Earlier [5] we have fabricated for the first time diode lasers with asymmetric barriers (LABs). Their experimental studies revealed that the introduction of ABLs leads to reduction in threshold current, increase in external differential quantum efficiency and decrease in internal optical losses near the lasing threshold, as well as increase in temperature stability. Moreover, recent calculations [6] have shown that ABLs are capable of suppression of light-current characteristic (LCC) saturation, associated with parasitic recombination, and thus to improve diode lasers power characteristics. In fact, more recent measurements [7] demonstrated moderate enhancement of LCC linearity owing to

ABLs. However, a low threshold of catastrophic optical mirror damage (COMD) due to utilization of narrow waveguide did not allow conducting measurements at high pumping, when a significant saturation of LCC takes place.

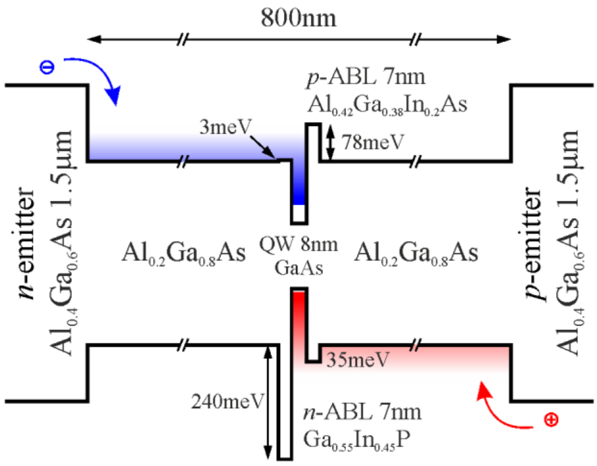

Figure 1. Schematic band diagram of studied LAB.

In the present work, we study experimentally the effect of ABLs on power characteristics of diode lasers of 850 nm spectral range with wide waveguide. We show that LAB is characterized by considerably more linear LCC as compared to the reference laser of conventional design without ABLs both at room and elevated temperatures.

2. Experiment

Studied laser diodes of 850 nm spectral range were fabricated from heterostructures of two types: with and without ABLs. Synthesis was performed by low pressure MOVPE on n^+-GaAs (100) substrates. The heterostructure without ABLs served as reference and, in fact, was a conventional heterostructure of a semiconductor quantum well (QW) laser for the given spectral region. A single GaAs QW of 8 nm width was placed in the middle of wide (800 nm) $Al_{0.2}Ga_{0.8}As$ waveguide. We used $Al_{0.4}Ga_{0.6}As$ for *n*- and *p*-type emitters with dopant concentration on the order of 10^{18} cm^{-3}. Silicon was used as the *n*-type impurity, while carbon was used as the *p*-type impurity.

The structure of the second type (Fig. 1) varied from the first structure in that its waveguide comprised two 7-nm-thick ABLs on both sides of the QW. $Ga_{0.55}In_{0.45}P$ was used as *n*-ABL, while $Al_{0.42}Ga_{0.38}In_{0.2}As$ – as *p*-ABL. The calculated energy barriers at the *n*-ABL/waveguide interface were 240 meV for holes and 3 meV for electrons, while those at the *p*-ABL/waveguide interface were 78 and 35 meV for electrons and holes, respectively. The band edge positions were calculated taking in account the effect of both the chemical composition and elastic strains. The lattice mismatch between ABLs and the substrate did not exceed 1.5%, which allowed a pseudomorphic synthesis of the structure.

Laser strips of 50 μm width were processed on the surface of epitaxial wafers by the standard postgrowth techniques including optical lithography, ion beam etching as well as deposition of metals and insulators. Laser with cavities of various lengths were fabricated by cleaving the crystals. No coatings were deposited onto the mirrors. The laser chips were then soldered with the *p*-side down on a copper heat sink. During measurements the heat sink temperature was stabilized with a temperature controller.

The saturation of LCC of diode laser may be due to its overheating (the so-called thermal rollover) or to the parasitic carrier recombination in the waveguide. To eliminate the influence of QW overheating on the device characteristics, the samples were pumped with short rectangular current pulses of 200 ns duration and low repetition frequency of 100 Hz. To measure the LCCs, we used a large area (1×1 cm^2) silicon photodiode mounted close to the sample. To eliminate saturation of the photodiode by high-power laser radiation, calibrated optical filters were mounted between the laser and the photodiode.

3. Results

Fig. 2 shows the dependence of the threshold current density on the cavity length for both types of lasers at 20ºC. The presented data corresponds to ground state lasing only. It is seen that the inclusion of ABLs in the heterostructure has insignificant effect on the threshold current. For example, 2-mm long laser diodes had threshold current of about 400 mA. The inset of Fig. 2 shows spectra of lasing emission via ground state optical transition of the LAB and the reference laser with 2 mm length measured at 20ºC and 2 A pumping current. It is seen that the lasing line in the LAB is blue shifted compared to the lasing line of the conventional reference laser without barriers. The lasing peaks of the LAB and the test laser are positioned at 841 and 853 nm, respectively. The reason for the lasing line blue shift is in that the additional barriers close to the active region lead to increase in ground state energy with respect to bottom of the QW and corresponding growth of the ground state optical transition energy.

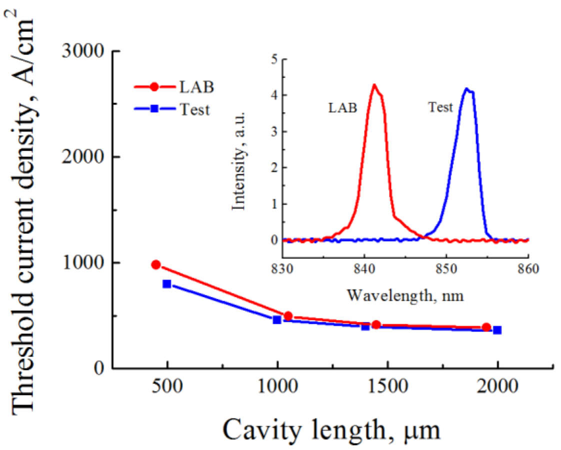

Figure 2. Threshold current density against cavity length for LAB and reference laser at 20ºC. Inset shows lasing emission spectra of 2-mm long lasers measured at 20ºC and 2 A current.

Fig. 3 shows the degree of deviation from linearity δ for the LCCs measured at 20 and 60ºC, calculated as $\{[\eta_0(I - I_{th}) - P] / \eta_0(I - I_{th})\} \times 100\%$, where η_0 is the external differential quantum efficiency determined in the initial part of the LCCs, near the threshold current I_{th}, I is the drive current and P is the measured output optical power. At room and elevated temperature the LAB demonstrates significantly better linearity of the LCC than the conventional laser without ABLs. Thus at 7(5) A the deviation from linearity δ in the test laser made 33(16)% against 9(5)% in the LAB at 20(60)ºC.

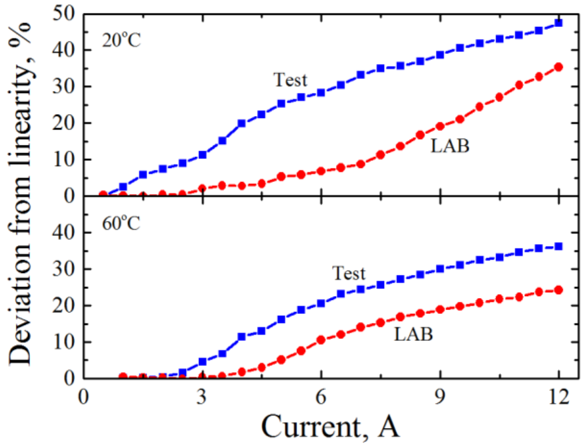

Figure 3. Current dependences of deviation from linearity for LCCs measured at 20 and 60ºC for LAB and test laser of 2-mm-length.

Output optical power dependences of the pumping current for both types of lasers of 2-mm-length at room and elevated temperatures are shown in Fig. 4. Owing to suppressed saturation of the LCC the same lasing power is achieved at a considerably lower operating current in the laser with ABLs as compared to the reference laser. For example, at 20(60)ºC output optical power of 8(6) W was reached with 45(17)% less pumping as a result of ABLs implementation. It should be mentioned that the maximum lasing power in both lasers is the same, being about 9 W at 20ºC and is limited by catastrophic optical mirror damage.

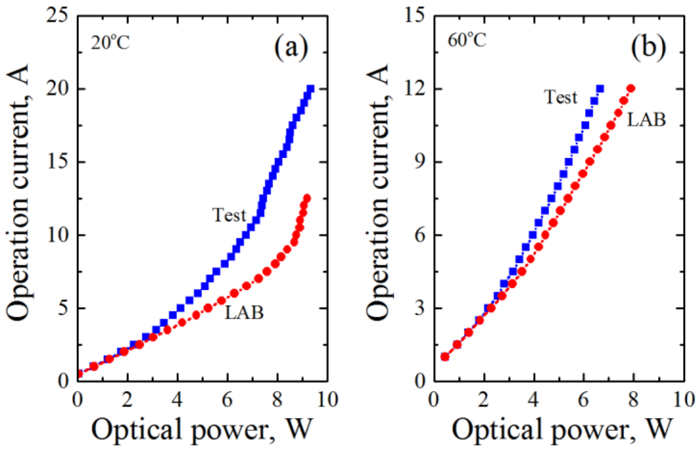

Figure 4. Operating current as a function of output optical power for LAB and the test laser at 20ºC (a) and 60ºC (b).

4. Conclusion

We have shown that the saturation of LCC in QW lasers at high pumping currents, which is caused by parasitic recombination in the waveguide, can be significantly suppressed by two ABLs adjoining the active region on both sides. This effect was observed at room and elevated temperatures. The deviation of LCC from linear dependence in the LAB was shown to be less dramatic as compared to that in the reference laser without ABLs. For example, at 20ºC and pumping current of 7 A the deviation of LCC from linearity in the test laser was as high as 33%, whereas it was only 9% in the LAB. While the maximum output power, being limited by the catastrophic optical mirror damage, is the same in both lasers, the operation current, at which it is reached, is more than 40% lower in the LAB as compared to the reference laser.

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